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# Pressure Measurements in a PBX 9501 Gauged Acceptor when Impacted by a Steel Plate that is Accelerated by a Thermally Cooked off PBX 9501 Charge

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# Pressure measurements in a PBX 9501 gauged acceptor when impacted by a steel plate that is accelerated by a thermally cooked off PBX 9501 charge*

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Measuring the violence of a thermal explosion of a cased explosive is important for evaluating safety issues of explosive devices in fires. A sympathetic initiation scenario was studied here where a 9.0 cm diameter by 2.5 cm thick disc of PBX 9501 donor charge encased in a 304 stainless steel assembly was heated on top and bottom flat surfaces until it thermally exploded. The initial heating rate at the metal/explosive interface was 5°C per minute until it reaches 170°C; then this temperature is held for 35 minutes to allow temperature equilibration to within a few degrees throughout the explosive. The heating resumed at a rate of 1°C per minute until the PBX 9501 donor thermally exploded. A PBX 9501 acceptor charge with carbon resistor and manganin foil pressure gauges inserted at various depths was placed at a 10 cm standoff distance from the donor charge's top steel cover plate. Piezoelectric arrival time pins were placed in front of the acceptor surface to measure the velocity and shape of the impacting plate. The stainless steel cover plate of the donor charge had a nominal velocity of 0.55 ± 0.04 mm/μs upon impact and was non-symmetrically warped. The impact of the tilted curved plate induced a three-dimensional compression wave into the acceptor. The rise times of the pressure waves were nominally 1.5 μs with the closest carbon resistor gauges giving peak pressure of 10 kb that decayed to 3 kb for a wave run distance of 2.4 cm.

## INTRODUCTION

The level of violence of thermal explosion events as a function of material condition, confinement, and thermal heating rates can only be determined experimentally. In addition, measuring acceleration of a metal case by a thermal reaction is necessary for assessing whether detonation or a low level reaction occurs in a neighboring explosive item being impacted by a donor's case. Results of thermal explosion events with known conditions are essential for developing and/or calibrating reactive flow computer models. Once calibrated these models can be used to calculate events that are difficult to measure experimentally

Three different experiments have been performed previously[1-3]. Two of these experiments thermally exploded stainless steel encased PBX 9501 (HMX/Estane/BDNPA-F; 95/2.5/2.5 wt %) donor charges. The donor charges design has been kept constant for all PBX 9501 experiments including the experiment reported in this paper. Gauges in the acceptor cylinder made of either Teflon or PBX 9501 measured transmitted two-dimensional pressure waves. The acceptors were in contact with the donor system's top steel plate. A third experiment measured the temperature distribution inside a Teflon disc substituting for the donor in the same metal fixture with the same heating rates used in the explosive donor experiments. The measured thermal history in the Teflon allows accurate calculation of the temperature-time history in the heated explosive donors up to where reaction begins.

## EXPERIMENTAL PROCEDURES

Experiment TEXT VII had the acceptor placed at a 10 cm standoff as shown in Figure 1. The heated PBX 9501 cylindrical donor is confined by 304 Stainless Steel. The HE disc and case was designed such that the explosive would come into contact with all surfaces when the explosive was at 150°C.

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The donor confinement was made up of a top 12.4 mm thick stainless steel plate fastened to the 12.4 mm bottom steel plate with several "grade-A" hardened steel bolts tightened to 95 N-m (70 ft-lbs). The 9.0 cm by 2.5 cm thick disk of PBX 9501 weighed 295 g was radially constrained by close fitting stainless steel ring with wall thickness of 34.5 mm. The ring height was slightly greater than the explosive at room temperature to allow the explosive and metal container to come into contact at 150°C. A 3 mm thick copper plate was placed between the front steel plate and the explosive to distribute the heat faster and more uniformly than would occur for just a steel plate. The copper plate also served as a gasket for a pressure seal since both steel interfaces had knife edges machined in them. The flat Nichrome spiral ribbon heater shown in Figure 2 was placed between the steel cover plate and the copper plate on both top and bottom. The two thermocouples in this heater package are to monitor temperature and control the heating rate of the heaters. No thermocouples were placed internal to the steel encased PBX 9501 to allow a simple pressure seal design for this steel fixture.

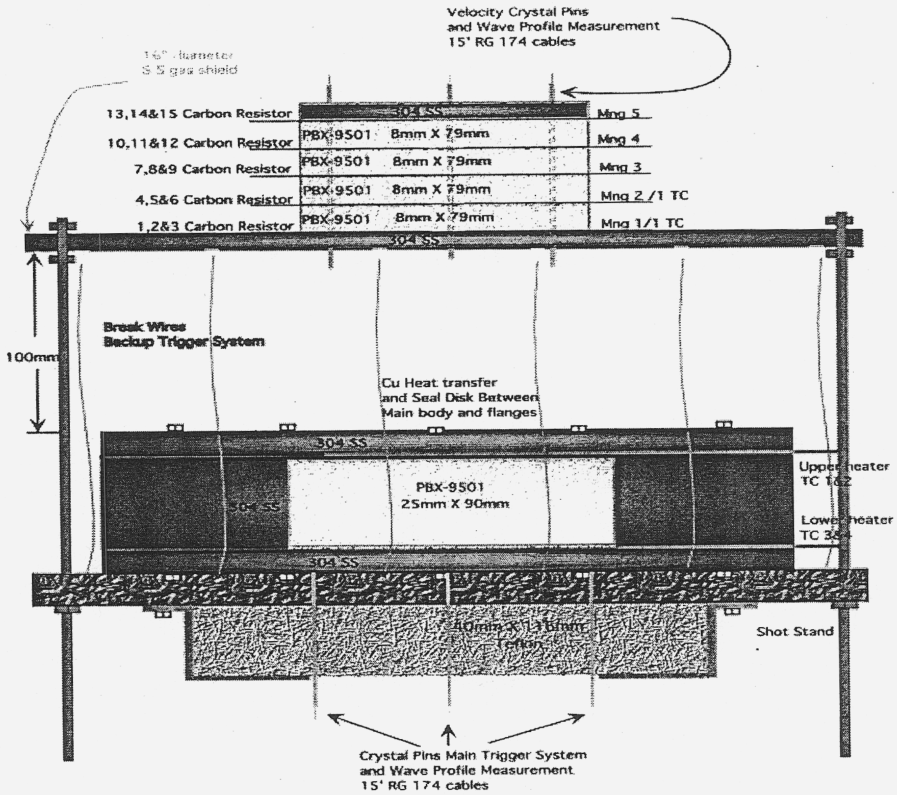


Figure 1. Schematic of TEXT VII gauged thermal explosion experiment

The manganin and carbon resistor gauges were embedded in 7.9 cm diameter acceptor discs of PBX 9501 at 0, 8,16, 24,and 32 mm from the steel plate the acceptor was sitting on. This steel plate was 10 cm from the top of the donor's steel top plate. A schematic of the gauge placement in the PBX 9501 discs is shown in Figure 2. The carbon resistor gauges were placed in machined grooves in the PBX 9501 disc surfaces. The manganin gauges were sandwiched between two 0.13 mm thick Teflon insulating sheets. These gauge packages were placed between the PBX 9501 acceptor discs.

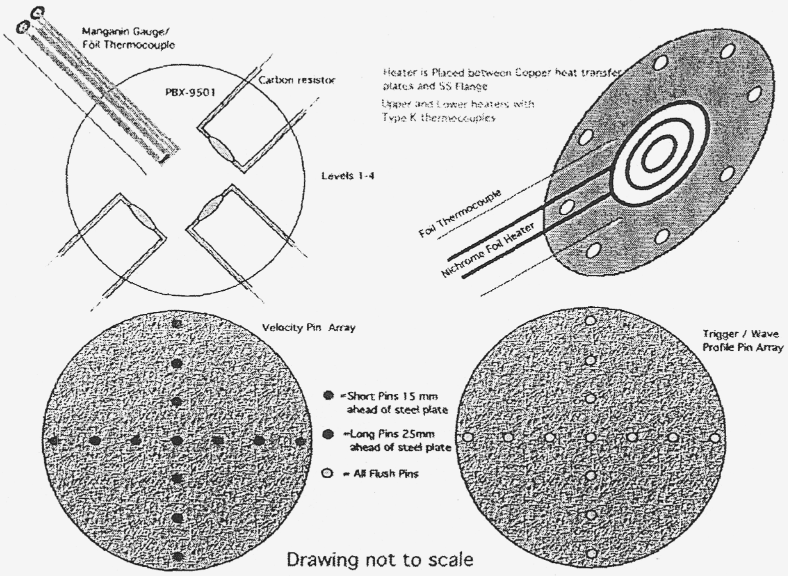


Figure 2. Heater / thermocouple and acceptor gauge/pin arrangements.

Carbon resistor and manganin foil gauges require a constant current source to allow direct correlation of the measured voltage change to resistance change. The change in resistance has been calibrated as a function of pressure for both of these gauges, which allows conversion of measured voltage signals to pressure. The constant current power supply for the carbon resistor gauges is always turned on sending 18 mA through the 470-ohm resistors. The constant current for the manganin gauges was provided by Dynasen CK2-50/0.050-300 power supply which powered the gauge with a constant current between 30-50 amperes. Carbon resistor gauges have been successfully used in two-dimensional shock wave experiments where time resolution was sacrificed for survival of the gauge.[1-7] The calibration of the carbon resistor gauge has been done by numerous researchers and their results along with some new data at low pressue are summarized in two recent papers.[8,9] Manganin foil gauges are well established for measurement of one-dimensional shock wave pressures.[10]

The triggering of the power supplies and the digitizers is a critical feature of this experiment. For the primary triggering system and to measure the wave arrival times at the bottom steel plate surface, a series of thirteen PZT pins were held in a Teflon disc and placed against the bottom steel plate of the donor assembly. The pins where in a cross pattern with one pin at the center and each pin being 11.7 mm center to center distance apart. These pins can be seen just below the acceptor in Figure 1. The thirteen PZT pins were all summed so that any one of them would trigger the digitizers and the power supply for the manganin gauge. A back-up break wire trigger system was also used. This system provided a trigger pulse from a circuit if any of the wires break. These break wires were also summed so the first one would trigger the digitizers and power supplies. The modern Tektronix TDS digitizer continuously records data until a trigger signal stops it. The digitizer then captures events ahead and behind the trigger signal at amounts determined by the chosen settings. This gives some flexibility in performing these cook-off experiments since there is always uncertainty in when and where the trigger signal will originate.

To measure the time of arrival of the accelerated top steel plate at the acceptor, another cross pattern of 13 PZT arrival pins was used. Five pins were placed 15 mm in front surface and eight were placed 25 mm in front of this steel acceptor plate. The placement of these pins within the acceptor can be seen in Figure 2.

Figure 3 is a photograph of the assembled experiment. This assembled experiment was placed inside a large steel cylinder to protect the firing chambers walls. Figure 4 shows the experimental assembly's location inside this steel tube that is placed inside the powder gun's firing chamber. This experiment was conducted in the gun's chamber because most of the electronics for gauge experiments are permanently setup in this facility.

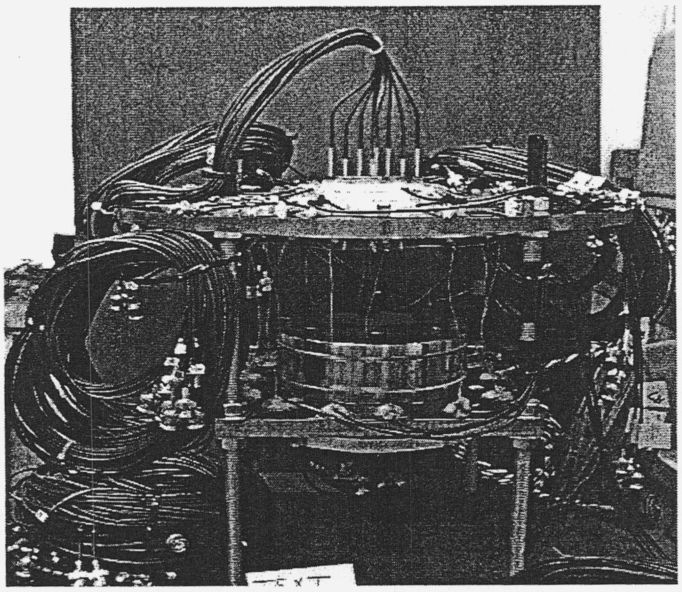

Figure 3. Picture of the assembled TEXT VII experiment

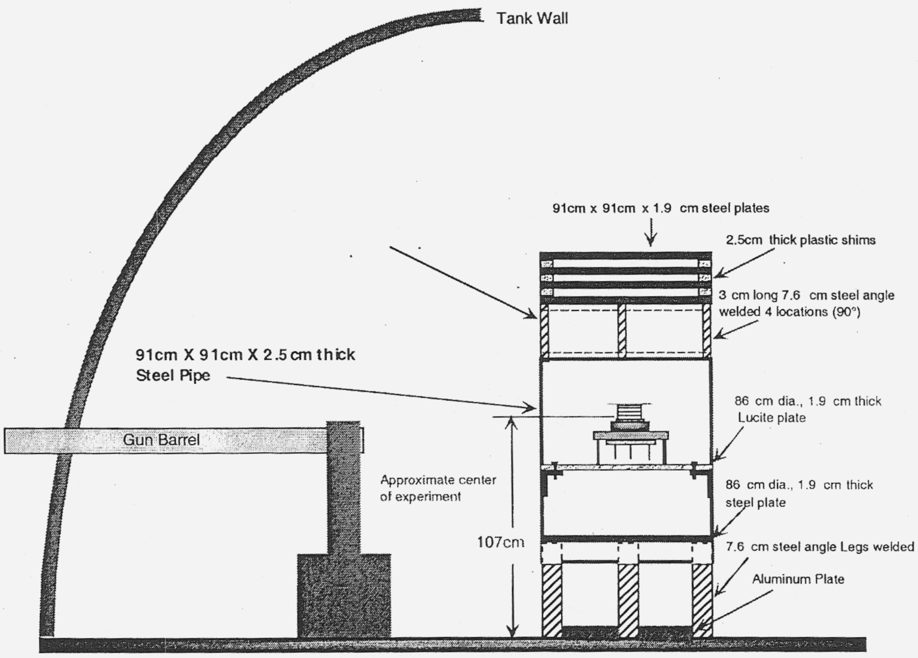


Figure 4 Experimental arrangement to protect the powder gun's firing tank wall

## RESULTS

The heating history provided by the thermocouple outputs for TEXT VII is given in Figure 5. Thermocouples 1-4 located in the donor heater packages (see Figure 1) went to 170°C at a rate of 5°C a minute. The controllers then allowed the heaters to overshoot to 175°C for 7 minutes and then brought the temperature back to 170°C for 30 minutes. The heating rate at the steel cover plate then went to 1°C/min until the temperature at the steel plate reached 210°C and the PBX 9501 inside the case went off. Thermocouples 5 & 6 where located at the interface between the acceptor's steel plate and the first PBX-9501 disc. These thermocouples showed only a few degrees rise in temperature during the experiment as expected.

The data from the trigger and arrival time pins at the bottom of the donor assembly indicates that a reaction pressure wave started near the center of the charge and the wave swept out from the center across the bottom steel plate. The pins near the center reported a rapid phase velocity of near 1.8 mm/μs while the velocity from the center to outer pins registered phase velocities near 1 mm/μs. This suggests that the PBX 9501 donor underwent a rapid burn reaction that bulged the center closing the center pins. The reaction then spread radially outward pushing the plate above the reaction front into the pins.

Figure 6 gives the measured contours of the flying top donor steel plate just before impacting the steel plate that the acceptor is sitting on. These contours were determined from the plate's velocity and arrival times at the array of pins ahead of the acceptor. The plate is traveling at an average velocity of 0.55 ± 0.04 mm/μs. Based on the limited pin data the flying plate had a oblate spheroid shape (i.e. shape of a door knob).

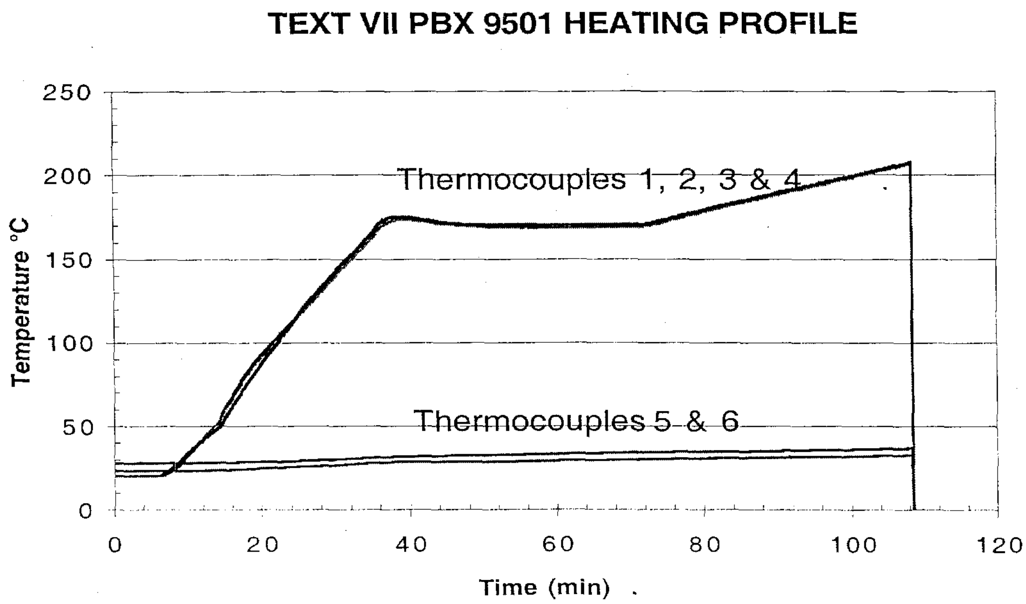


Figure 5. Temperature profiles of various thermocouples at various locations in the TEXT VII assembly

The carbon resistor gauge records are given in Figure 7. The ramp wave's peak pressure decays rapidly as the wave travels through the acceptor. The pressure wave has a peak of 10 kb at the first PBX 9501 acceptor disc decreasing to 4 kb after a 32 mm run distance into the

PBX 9501acceptor as shown in Figure 7. The ramp wave in these records and extra structure is due to the three-dimensional loading of the warped flyer plate.

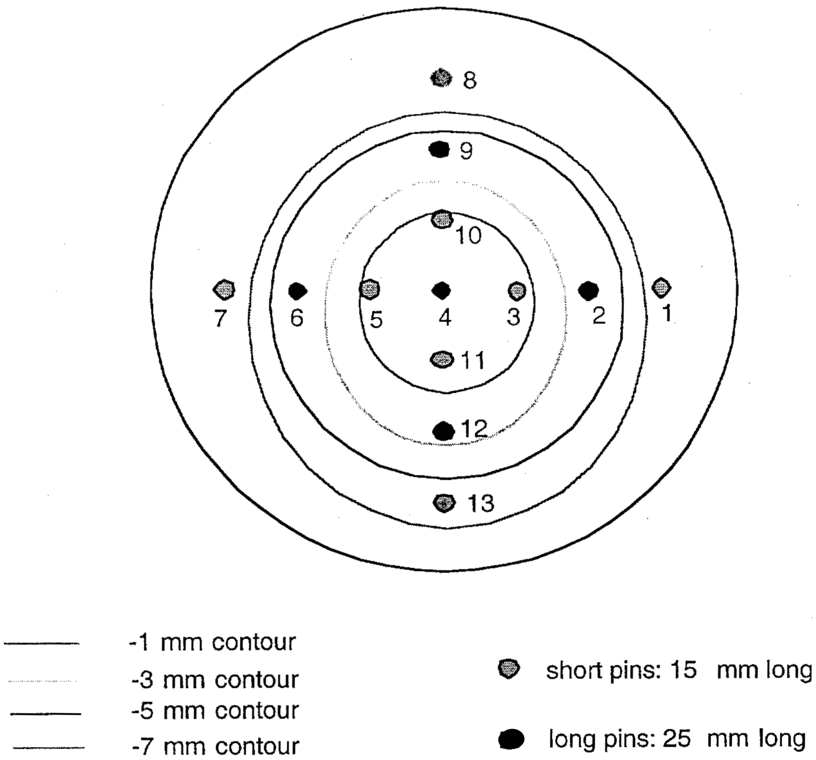


Figure 6. Contours of the impact plate, accelerated by the thermal explosion of the donor with numbers that indicate depth of the plate surface relative to impact.

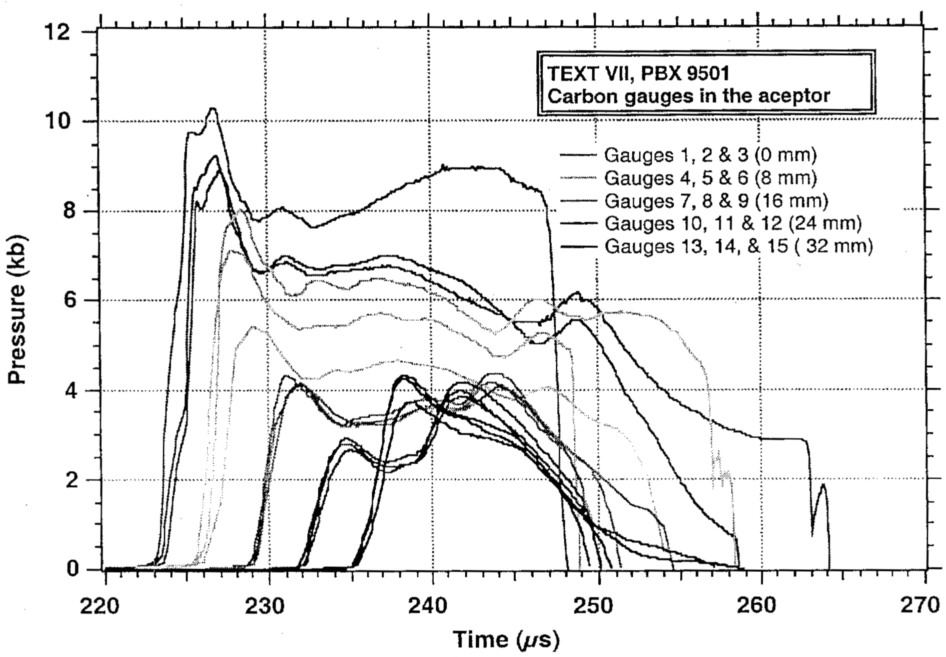


Figure 7. Carbon resistor gauge records for TEXT VII experiment.

The wave did not build into a high-pressure wave or a detonation so the manganin gauge signals were very small at first and then increased significantly when the lateral strain in the gauge became large. These records are of limited value and not reported here.

## MODELING OF EXPERIMENT

The experimental geometry shown in Figure 1 was modeled in the DYNA2D hydrodynamic computer code. The PBX 9501 was assumed to deflagrate at approximately 1000 m/s from its bottom surface toward the steel plate to be accelerated into the PBX 9501 acceptor using the DYNABURN option of the code. DYNABURN is an outgrowth of the widely used Ignition and Growth reactive flow model for shock initiation and detonation wave propagation in solid explosives. A small initial pressure initializes DYNABURN and/or fraction reacted in the elements where the reaction is known or assumed to begin. A subsonic deflagration wave is then propagated using the pressure and particle geometry dependent growth of reaction terms of the Ignition and Growth model. This reactive flow option has been used to model air bag propellants, internal ballistics of guns, explosive and propellant deflagration, and other violence of thermal explosion experiments[11]. The calculated deflagration wave for this experiment accelerated the steel plate to 0.51 mm/µs at impact with the steel confinement of the PBX 9501 acceptor charge. This velocity is within the uncertainty in the experimental measurement, 0.55 +/- 0.04 mm/µs. Figure 8 shows the resulting calculated pressure histories in the PBX 9501 acceptor charge at the 0, 8, 16, 24, and 32 mm depths where the carbon resistor gauges were located.

The general agreement between these calculated records and the carbon gauge records in Figure 7 show that these resistor gauges are recording the peak pressures and pulse durations with accuracy better than 20%. The attenuation of the peak pressures is faster in the experiments than in the calculation that will be addressed in future work. Note also that the pressure release in the calculations is faster than in the gauge records. The carbon resistor gauges have a hysteresis upon release of pressure. Understanding this result requires further calibration of the gauge upon release. The Ignition and Growth reactive flow model for the shock initiation of PBX 9501, which has been normalized to a great deal of experimental data from LANL, predicts no significant exothermic reaction in this PBX 9501 acceptor charge. Therefore, the model results imply that no shock initiation and subsequent buildup to detonation will occur from this type of thermal explosion test. This is consistent with the results of other thermal explosion experiments on HMX-based PBX's containing 85 - 95% HMX.

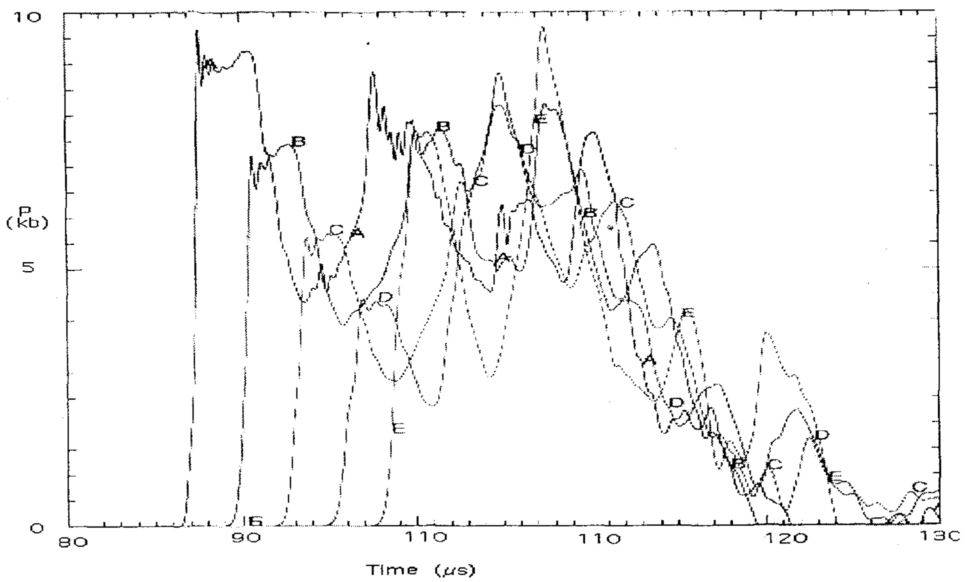


Figure 8. DYNA2D hydrodynamic modeling of TEXT VII

## SUMMARY AND CONCLUSIONS

A multi-dimensional ramp pressure wave is transmitted to the PBX 9501 acceptor from a steel plate accelerated by the thermal explosion of a confined PBX 9501 donor system. The peak pressure in the PBX 9501 acceptor was 10 kb decreasing to 4 kb at a 32 mm run distance. The ramp wave features and extra structure in these records are due to the three-dimensional loading from the tilted curved flyer plate's impact. The measured pressures are substantial and will scatter burning materials around, but will not build-up to detonation in the accepter under these experimental conditions. The DYNA2D modeling of this experiment gives results which are in good agreement with the experiment.

Future work on this area will include experiments on another HMX based explosive LX - 04, which contains 85 wt. % HMX and 15 wt.% Viton A binder. Experiments with well-characterized damaged high explosives, different heating rates, and confinement are being considered for future experiments. A thermal and hydrodynamic coupled code ALE 3D will be used to model the results of these and future experiments.


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## REFERENCES


1. Urtiew, P. A., Forbes, J. W., "Experimental Study of Low Amplitude, Long-Duration Mechanical Loading of Reactive Materials", 19th Propulsion Systems Hazards Subcommittee (PSHS) Meeting, Monterey, CA. 13-17 November (2000).

2. Forbes, J. W.,Tarver C.M., Urtiew, P. A., Garcia, F., Greenwood, D. W., and Vandersall, K.S. "Pressure Wave Measurements from Thermal Cook-off of an HMX Based Explosive," 50th Joint Propulsion Meeting, Salt Lake City, UT 11-13 July 2001.

3. Garcia, Frank, Forbes, Jerry W., Tarver, Craig M., Urtiew, Paul A., Greenwood, Daniel W., Vandersall, Kevin S., "Pressure Wave Measurements From Thermal Cook-Off Of An HMX Based High Explosive PBX 9501", Proceedings of Shock Compression of Condensed Matter-2001, June 24-29, 2001 in Atlanta, GA

4. Ginsberg, Michael J., and Asay, Blaine W., "Commercial Carbon Composition Resistors as Dynamic Stress Gauges in Difficult Environments," Rev. Sci. Instrum. 62 (9): 2218-2227 (1991).

5. Wilson, W. H., "Experimental Study of Reaction and Stress Growth in Projectile-Impacted Explosives," Shock Compression of Condensed Matter-1991, eds. Schmidt, Dick, Forbes, and Tasker, Elsevier Science Publishers, pp. 671-674 (1992).

6. Austing, J. L., Tulis, A. J., Hrdina, D. J., and Baker, D. E., "Carbon Resistor Gauges for Measuring Shock and Detonation Pressures I. Principles of Functioning and Calibration", Propellants, Explosives, Pyrotechnics 16, pp. 205-215 (1991).

7. Forbes, J. W., Tarver, C. M., Chidester, S. K., Garcia, F., Greenwood, D. W., Garza, R, "Measurement of Low Level Explosives Reaction in the Two-dimensional Steven Impact Test" 19th Propulsion Systems Hazards Subcommittee (PSHS) Meeting, Monterey, CA. 13-17 November (2000)

8. Cunningham, B., Vandersall, K. S., Niles, A. M., Greenwood, D. W., Garcia, F., Forbes, J. W., and Wilson, W. H., "Carbon Resistor Pressure Gauge Calibration at Low Stresses," Proceedings of Shock Compression of Condensed Matter-2001, June 24-29, 2001 in Atlanta, GA.

9 Vandersall, Kevin, S., Niles, Angel M., Greenwood, Daniel W., Cunningham, Bruce, Garcia, Frank, Forbes, Jerry W., "Carbon Resistor Pressure Gauge Calibration At Stresses Up To 800 Mpa", 20th Propulsion Systems Hazards Subcommittee (PSHS) Meeting, Destin, FL., 8-12 April (2002).
10. Vantine, H. S., Erickson, L. M., and Janzen, J., "Hysteresis Corrected Calibration of Manganin under Shock Loading," J. Appl. Phys., 51, (4), 1980.
11. Chidester, S. K., Tarver, C. M., Green, L. G., and Urtiew, P. A., "On the violence of thermal explosion in solid explosives," Comb. And Flame **110**, pp. 264-280 (1997).